

FULL-SCALE TESTS OF CHANNEL SHEAR CONNECTORS AND COMPOSITE T-BEAMS

BY

IVAN M. VIEST

Ing., Slovak Technical University, Czechoslovakia, 1946
M.S., Georgia School of Technology, 1948

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The tests reported in this thesis were made as part of an investigation of slab and beam highway bridges conducted at the Talbot Laboratory by the Engineering Experiment Station of the University of Illinois in cooperation with the Illinois Division of Highways and the Bureau of Public Roads of the U. S. Department of Commerce.

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INTRODUCTION

One of the most common types of highway bridges in current use is the I-beam bridge which consists of several steel I-beams supporting a reinforced concrete floor slab cast on top of the beams. If an adequate connection is provided between the beams and the slab, the slab and the beams act as a composite structure. Laboratory tests reported in this thesis were made on full-scale composite T-beams and push-out specimens to provide experimental evidence regarding the behavior of composite structures of this type.

The chief purpose of the tests was to determine (1) the behavior of composite T-beams, (2) the effect of shoring on the behavior of composite T-beams and (3) the behavior of channel shear connectors. Data for studies of the first two questions were obtained from the tests of composite T-beams. The behavior of channel shear connectors and the influence of a number of variables on their behavior were investigated in the tests of push-out specimens.

PUSH-OUT TESTS OF CHANNEL SHEAR CONNECTORS

Tests of 43 push-out specimens are reported in this thesis. The specimens consisted of two concrete slabs each connected to the flanges of an I-beam by a single shear connector. Most of the shear connectors were made of rolled steel channels; in few specimens, however, connectors made of steel plates or square bars were used. The shear connectors were welded to the beam flanges.

The principal variables in these push-out tests were the strength of the concrete, the dimensions of the channel connectors, the restraint of concrete under the connector, and the direction of the load. The concrete strength varied from

2070 to 6320 psi. The dimensions of the channel shear connectors varied as follows:

- (a) Thickness of channel web: 3/16 in. to 8/16 in.
- (b) Thickness of channel flange: 0.377 in. to 0.944 in.
- (c) Height of channel: 3 in. to 5 in.
- (d) Width of channel: 4 in. to 8 in.

In most specimens the slabs were cast flush with the flanges of the I-beam. However, in some specimens a concrete fillet was placed between the flanges and the slab in order to decrease the restraint of the concrete under the connectors.

All specimens were tested with static loading. In some tests the load was increased continuously until failure occurred; in others the load was released and reapplied a few times before failure was reached. Slip between the beam and the slabs, and strains on one of the shear connectors were the only measurements made in these tests.

All results of the tests of push-out specimens lead to the conclusion that a channel connector acts as a dowel. The largest part of the load transmitted by a channel connector is carried by the sections adjacent to the beam. Consequently, large pressure is concentrated on the concrete located next to the beam. The maximum steel stresses occur at the fillet between the web and the welded flange of the channel connector.

The results of these tests give conclusive evidence that the large concentration of pressure on the concrete is not dangerous. Stresses several times larger than the compressive cylinder strength can exist safely under a channel connector because a state of triaxial compression is present at that location.

It was found that the load-carrying capacity of a channel connector increased with increasing width of the connector and thickness of the channel flange welded to the beam. An increase in the thickness of the channel web or an increase in the concrete strength resulted in a small increase of the

capacity of connector, while the height of the channel did not affect this capacity.

ANALYSIS OF CHANNEL SHEAR CONNECTORS

The theoretical analysis of the behavior of channel connectors presented in the thesis is basically a modification of the well-known theory for semi-infinite beams on elastic foundations. This theory makes it possible to calculate moments, shears and deformations at any section of a channel shear connector as long as the steel stresses are below the yield point.

Since the theoretical equations are too complicated for design purposes, they are simplified by the introduction of several assumptions. These simplified design formulas can be used only for prediction of the maximum steel stresses, the maximum pressure on the concrete, and the slip between the slab and the beam.

Both the theoretical equations and the simplified design formulas are compared with the results from the tests of push-out specimens and T-beams. The comparisons show a reasonably good agreement.

TESTS OF COMPOSITE T-BEAMS

Tests of four composite steel and concrete T-beams with span lengths of 37.5 ft are reported. Each T-beam consisted of a simply-supported rolled steel wide-flange beam, supporting a reinforced concrete slab on the top flange. The connection between the slab and the beam was provided by channel shear connectors.

The variables in these tests were the size of the steel I-beam and the stiffness of the shear connection. Two of the T-beams were built with shoring and two without.

All tests were made with a static concentrated load simulating the effects of a truck wheel load. The load was located at one of three points: (1) midspan, (2) quarter point,

(3) close to the support.

Measurements included strains on the slab, beam, and shear connectors; deflections of the beam, and slip between the slab and the beam. On one beam vertical movements of the slab with respect to the beam were also measured.

The results of the tests are compared with theories for complete, incomplete, and no interaction; they are in excellent agreement with the theory for incomplete interaction. However, in three beams the degree of interaction was so high that the theories for incomplete and complete interaction gave practically the same results. A somewhat lower degree of interaction was observed on the fourth beam which was built with an extremely weak shear connection.

These tests showed that a composite T-beam is a tough structure; it has high reserve strength after the first yielding occurs and the ultimate load is reached only after large deflections have taken place. In the three beams with an adequate shear connection, the capacity beyond first yielding of the steel I-beams was on the order of 40 percent of the ultimate load, while the similar reserve strength without interaction between the beam and the slab was estimated to be about 10 percent. In these beams a practically complete interaction existed until the ultimate load was reached. On the other hand, the shear connection of the fourth beam permitted large slips after the first yielding of the steel beam and a large decrease of the reserve strength was observed.

A shear connection made of channel connectors will insure practically complete interaction up to the ultimate load if the maximum stresses in the connectors located close to the supports do not exceed the yield point stress before failure of the beams is reached.

On the basis of these results it is recommended that the shear connection for a composite T-beam be made strong enough to insure practically complete interaction until the ultimate flexural load is reached. If this is done, T-beams may

be designed on the basis of full interaction between the beam and the slab.

The tests of the T-beams also included information on the effect of shoring on the behavior of composite T-beams, the tendency of the slab to separate from the beam, the distribution of strains across the slab, and the effectiveness as shear connection of bond between the slab and the upper flange of the beam.

APPENDIXES

The assumptions made in computing the deformations of composite beams stressed beyond the elastic limit are discussed in one appendix, and a selective bibliography is given in another. The bibliography contains references to the following topics: (1) tests and design of composite concrete and steel T-beams; (2) tests, design, construction, and description of bridges of composite construction; (3) tests, design, and description of shear connectors; and (4) the theory of composite beams.

VITA

Ivan Miroslav Viest was born in Bratislava, Czechoslovakia, on October 10, 1922. After graduation from the First State Slovak Gymnasium of that city in 1941, he entered the Slovak Technical University. In 1944 his studies were interrupted for one year during which period he first took an active part in the resistance movement and later enlisted in the Czechoslovak Army; he received an honorable discharge in July 1945. He then continued in his studies and received his engineering diploma, with highest honors, from the Slovak Technical University in October 1946. After a short period of employment, he was awarded a scholarship by the Rotary Clubs of Georgia and entered the Georgia School of Technology in September 1947, where the degree of Master of Science in Civil Engineering was conferred upon him in June 1948. He began his studies in the Graduate College of the University of Illinois in September of the same year.

While attending the university in Czechoslovakia, he worked with the contractor R. Fric; after graduation he enlarged on his field and office experience while

employed with the Lana Construction Company, Bratislava, the contractors Barge and Thompson, Atlanta, and the architects Bush-Brown, Gailey and Hefferman, Atlanta. During his last year at the Slovak Technical University he held the position of Assistant to the Professor of Steel Building Structures. At the University of Illinois he held a Research Assistantship in Theoretical and Applied Mechanics from September 1948 to June 1950, when he was appointed a Research Associate. At this institution he was assigned to the cooperative investigation of reinforced concrete highway bridges.

He is a junior member of the American Society of Civil Engineers and the American Concrete Institute, a member of the Czechoslovak Society of Engineers and the Society of Sigma Xi. He is co-author of two papers on the use of electric strain gages in reinforced concrete research and co-author of two papers on the tests of small-scale shear connectors and composite T-beams.

